

Late Cretaceous Uplift in the Malargüe fold-and-thrust belt (35°S), southern Central Andes of Argentina and Chile

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ABSTRACT. The Cordillera de los Andes is the typical example of a subduction-related orogen. Its present topography is the result of post-Miocene uplift, however, Andean compressional deformation and uplift started in the Late Cretaceous, as increasingly recognized in different sectors of the mountain belt. We present evidences of a Late Cretaceous event of compressional deformation in the southern Central Andes (35°S), reflected in syn-orogenic foreland basin deposits assigned to the Neuquén Group in Argentina and the Brownish-Red Clastic Unit in Chile. Comparison of the facies of these units allows us to recognize a sector proximal to the Late Cretaceous orogenic front, a distal sector with sediment provenance from the forebulge and a western sector where the sediments were deposited within the Late Cretaceous mountain belt. On this basis, we assign the orogenic front to an inverted Jurassic normal fault, the Río del Cobre fault, and reconstruct the structure of the easternmost Late Cretaceous Andes at this latitude. The change in the location of the orogenic front north and south of 35°S allows us to recognize a long-lived change in behavior in Andean evolution in this sector, which correlates with a change in the shape and the deposits of Mesozoic Neuquén basin.

Keywords: Andes, Orogeny, Cretaceous, Foreland basin.

RESUMEN. Levantamiento Cretácico Tardío en la faja plegada y corrida de Malargüe (35°S), Andes Centrales del sur, Argentina y Chile. La Cordillera de los Andes es el ejemplo típico de un orógeno asociado a subducción. Si bien su topografía actual es el resultado del levantamiento posterior al Mioceno, la deformación y el levantamiento ándicos comenzaron a partir del Cretácico Tardío, como se reconoce actualmente en diversos sectores de la faja montañosa. En este trabajo se presentan evidencias de un evento de deformación compresiva durante el Cretácico Tardío en los Andes Centrales del sur (35°S) reconocido a partir de los depósitos sinorogénicos asociados, que se asignan al Grupo Neuquén en Argentina y la 'Unidad Clástica Café-Rojiza' (BRCU) en Chile. Mediante las variaciones de facies en estos depósitos se pueden reconocer un sector proximal cercano al frente orogénico Cretácico Tardío, un sector distal con aporte desde el dorso periférico, y un sector occidental en el que los depósitos se produjeron dentro del cordón montañoso. De esta manera, se puede ubicar el frente orogénico Cretácico Tardío, el que asignamos a la inversión tectónica de una falla normal jurásica, la falla Río del Cobre. El cambio en la ubicación del frente orogénico Cretácico al norte y sur de 35°S permite reconocer a este sector como un límite entre sectores con diferencias en su evolución andina, que se interpreta como heredado de la evolución de la cuenca Neuquina.

Palabras clave: Andes, Orogenia, Cretácico, Cuenca de antepaís.

1. Introduction

The Cordillera de los Andes is one of the most extensive mountain ranges in the world, extending for more than 8,000 km along the western margin of South America. In its central portion, it is the result of the subduction of the oceanic Nazca plate below the continental South America plate, being the typical example of a subduction-related orogen (Dewey and Bird, 1970; Oncken *et al.*, 2006). The present configuration of the range is mostly the result of Cenozoic deformation and uplift (*e.g.*, Jordan *et al.*, 1983; Mégard, 1984; Ramos, 1999; Vicente, 2005). However, in many sectors of the Andes, the first stage of Andean uplift took place in the Late Cretaceous. This stage has been recognized in the Peruvian Andes (Steinmann, 1929; Aubouin *et al.*, 1973; Vicente *et al.*, 1979; Mégard, 1984); the north Andes of Ecuador, Colombia and Venezuela (Aspden *et al.*, 1992; Jaimes and de Freitas, 2006; Martin-Gombojav and Winkler, 2008), the Central Andes in Bolivia (Sempere, 1995), and the Patagonian Andes (Biddle *et al.*, 1986; Fildani *et al.*, 2003).

In the southern Central Andes, the intense Cenozoic deformation overprinted previous events, making their recognition difficult. However, south of 36°S, Upper Cretaceous continental deposits known as the Neuquén Group have recently been interpreted as syn-orogenic strata corresponding to a Cretaceous foreland basin (Cobbold and Rossello, 2003; Ramos and Folguera, 2005). Based on detrital zircon ages, Tunik *et al.* (2010) dated the beginning of the exhumation in the Cordillera Principal and the maximum age of deposition of syn-orogenic strata in this basin as taking place in the early Cenomanian. In this contribution, we will present evidence for a Late Cretaceous age for the beginning of Andean uplift and deformation at 35°S, and we will address the issue of the location of the Late Cretaceous orogenic front north of 36°S. This will allow us to discuss some of the characteristics of this deformational event.

2. Geologic setting: the Neuquén basin

The Neuquén basin is a Mesozoic retroarc basin developed in the western edge of the Gondwana continent, sporadically open to the Pacific Ocean at its western margin (Fig. 1). Its infill comprises a thick succession of sediments, with the interplay between tectonics, sea level and activity in the

volcanic arc controlling the development of marine *versus* continental conditions (Legarreta and Uliana, 1996). The basin presents two distinct sectors: north of ~35°S, it comprises a narrow north-south trough (90 km wide), while south of this latitude it extends eastwards in the so-called Neuquén embayment, where it reaches a width of 300 km (Fig. 1). The history of the basin starts in the Late Triassic with the development of isolated hemigrabens, controlled by normal faults (Legarreta and Gulisano, 1989; Cristallini *et al.*, 2009; Giambiagi *et al.*, 2009; Fig. 1). Triassic-Jurassic synrift deposits consist of more than 2,000 m of fluvio-lacustrine and fan-delta deposits in the northern sector, and over 4,000 m of volcanic and volcanoclastic rocks in the Neuquén embayment (Gulisano and Gutiérrez-Pleimling, 1994; Manceda and Figueroa, 1995; Giambiagi *et al.*, 2009; Bechis *et al.*, 2010). Marine rift sequences unconformably overlay these continental deposits (Legarreta and Uliana, 1996; Lanés *et al.*, 2008). Since the Pliensbachian, when the depocenters were connected during a generalized marine transgression, the infill of the basin consisted in an alternance of continental and marine deposits (Legarreta and Uliana, 1999; Veiga *et al.*, 2005). Figure 2 shows the units of the infill at 35°S. Eventually, the beginning of widespread contractional deformation and the rise of the Andes led to the development of a foreland basin setting. Traditionally, this was interpreted as taking place during the latest Cretaceous to Paleogene, as evidenced in the deposits of the Malargüe Group which record the first Atlantic transgression in the Neuquén basin (Weaver, 1927), pointing out the change of the basin slope associated with the Andean uplift (Barrio, 1990; Aguirre-Urreta *et al.*, 2011). In recent investigations, it has been proposed that the foreland basin stage began earlier, in the early Late Cretaceous, with the deposition of the Neuquén Group (see section 3 below).

3. The Neuquén Group: syn-orogenic deposits of the initial Cretaceous uplift of the Andes

The Neuquén Group (Digregorio, 1972; Cazau and Uliana, 1973) corresponds to a Late Cretaceous sedimentary succession of clastic continental deposits which presents a maximum thickness of 1,500 m (Legarreta and Gulisano, 1989; Legarreta and Uliana, 1999). It crops out in the eastern sector of the Andes of southern Mendoza and Neuquén. Red sandstones

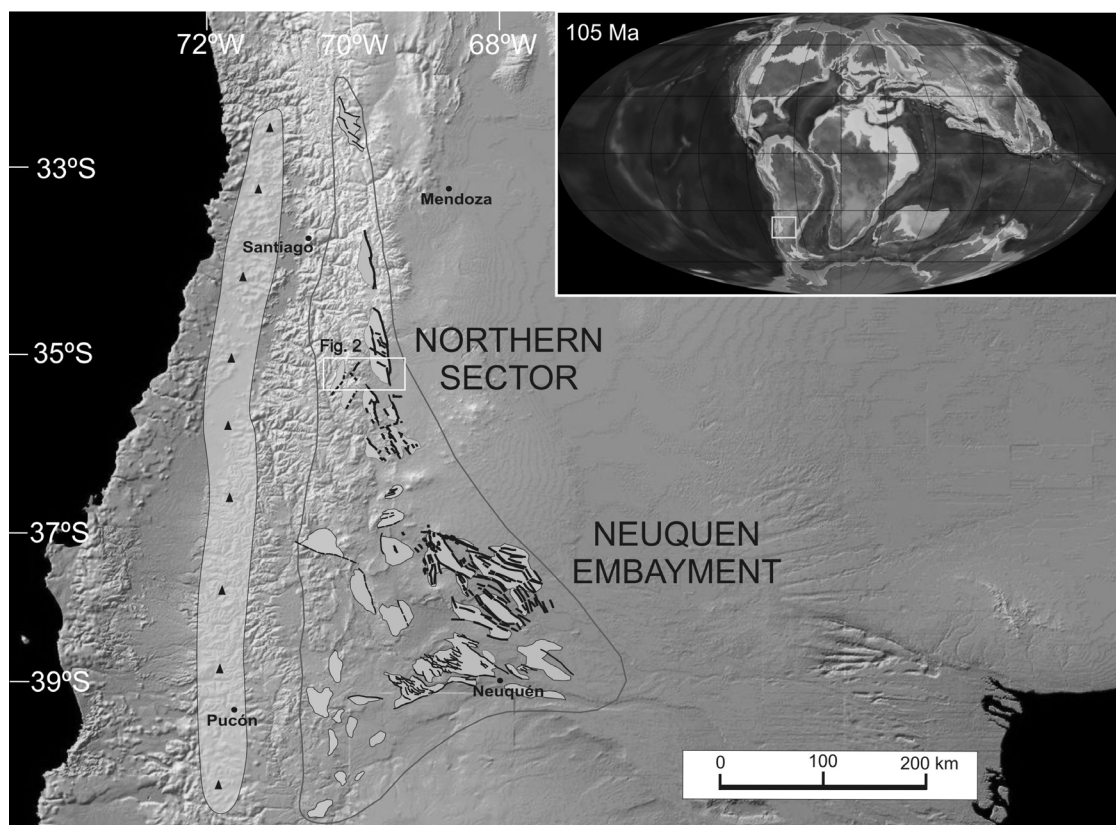


FIG. 1. Geologic setting of the Neuquén basin. Inset shows the location of the basin during the break-up of Gondwana in the Albian (paleogeographic map from Blakey, 2010). Main figure over GTOPO30 digital elevation model (available at http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/gtopo30_info (last accessed 24/10/2012)). The white box shows the location of figure 3. Limits of the Neuquén basin marked by the grey line. The fault-controlled isolated depocenters of Late Triassic to Early Jurassic age are also shown (according to Cristallini *et al.*, 2009 and Giambiagi *et al.*, 2009). The generalized location of the Mesozoic magmatic arc is also indicated.

and shales predominate, though intercalations of grey conglomerates and conglomeratic sandstones are found in the base of the succession at many localities, giving place to an upward-fining arrangement (Gerth, 1925, 1931; Cruz *et al.*, 1989; Legarreta and Gulisano, 1989). The basal contact with the underlying units is unconformable (Keidel, 1925; Gerth, 1931; Legarreta and Gulisano, 1989; Barrio, 1990; Leanza, 2009; Tunik *et al.*, 2010).

A fluvial environment is interpreted for this unit (Cazau and Uliana, 1973), including braided and meandering fluvial environments (Cruz *et al.*, 1989; Legarreta and Gulisano, 1989). In the eastern part of the basin, Armas and Sánchez (2011) have reported estuarine deposits in this unit, which could be related to the high sea-level which characterized the Late Cretaceous (Muller *et al.*, 2008).

According to Legarreta and Gulisano (1989), the age of the Neuquén Group is Cenomanian to Campanian (94 to 80 Ma). In the southern part of the Neuquén basin, in the locality of Cerro Policía (39°S), Corbella *et al.* (2004) obtained a zircon fission-track age of 88 ± 3.9 Ma for a tuff interbedded in the lower section of the Neuquén Group, which confirms the Late Cretaceous age of this unit.

The interpretation of the Neuquén Group deposits as syn-orogenic foreland basin deposits has been advanced by Keidel (1925) in the Neuquén province. This view was supported by other pioneer investigators such as Groeber (1929) and Wichmann (1934). However, in later works some authors interpreted that the deposition of the Neuquén Group took place during a period of tectonic quiescence, with thermal subsidence or magmatic load generating the accom-

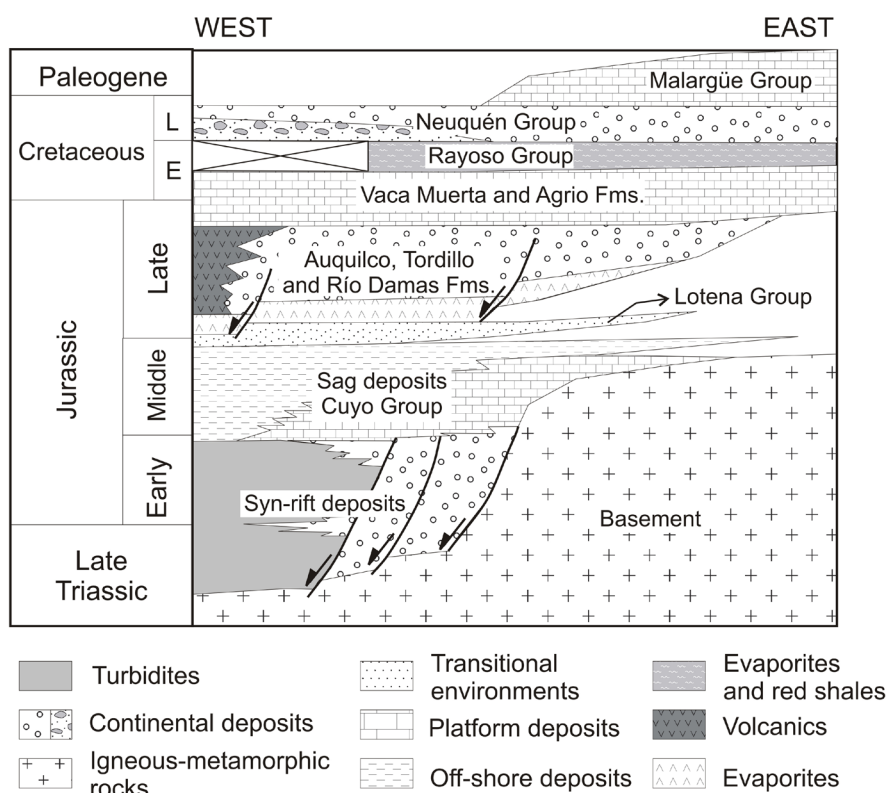


FIG. 2. Simplified stratigraphy of the Mesozoic units of the Neuquén basin at 35°S.

modation space (Uliana and Biddle, 1988; Legarreta and Gulisano, 1989; Legarreta and Uliana, 1998), while others followed Keidel's proposal of a Late Cretaceous orogenic phase (Stipanovic and Rodrigo, 1970; Ramos, 1988). Recent works focused on the outcrops of the Neuquén Group south of 36°S have strengthened the idea of interpreting these beds as syn-orogenic foreland basin deposits (Zapata *et al.*, 2002; Cobbold and Rossello, 2003; Ramos and Folguera, 2005; Zamora Valcarce *et al.*, 2006; Tunik *et al.*, 2010; Di Giulio *et al.*, 2010).

In particular, Tunik *et al.* (2010) have shown that there is a change in the provenance areas between the Neuquén Group and the underlying units through U-Pb dating of detrital zircons. The Aptian to Albian Rayoso Formation presents zircons derived from the cratonic basement located to the east and southeast of the Neuquén basin. In contrast, samples from the Neuquén Group present zircons with Early Cretaceous ages, which can only be attributed to the exhumation of the Andean magmatic arc located

to the west (Figs. 1 and 7), indicating a period of compressional deformation and uplift.

4. The Neuquén Group at 35°S

At 35°S latitude, the Andes of Argentina correspond to the Malargüe fold-and-thrust belt, a mountain range with altitudes between 2,000 and 4,500 m, uplifted between the Early Miocene and the present (Kozłowski *et al.*, 1993; Giambiagi *et al.*, 2008; Silvestro *et al.*, 2005). Figure 3 shows a simplified geologic map of the Andes at 35°S, with the distribution of the outcrops of the Neuquén Group. During the Cenozoic uplift (Combina and Nullo 1997, 2011; Mescua, 2011), the Mesozoic rocks were exposed and eroded. As a result of its stratigraphical position, high in the Mesozoic succession, the Neuquén Group was eroded away in many areas of the Malargüe fold-and-thrust belt, and at 35°S only minor relict exposures of this unit are found in two sectors of the Argentinean Andes.

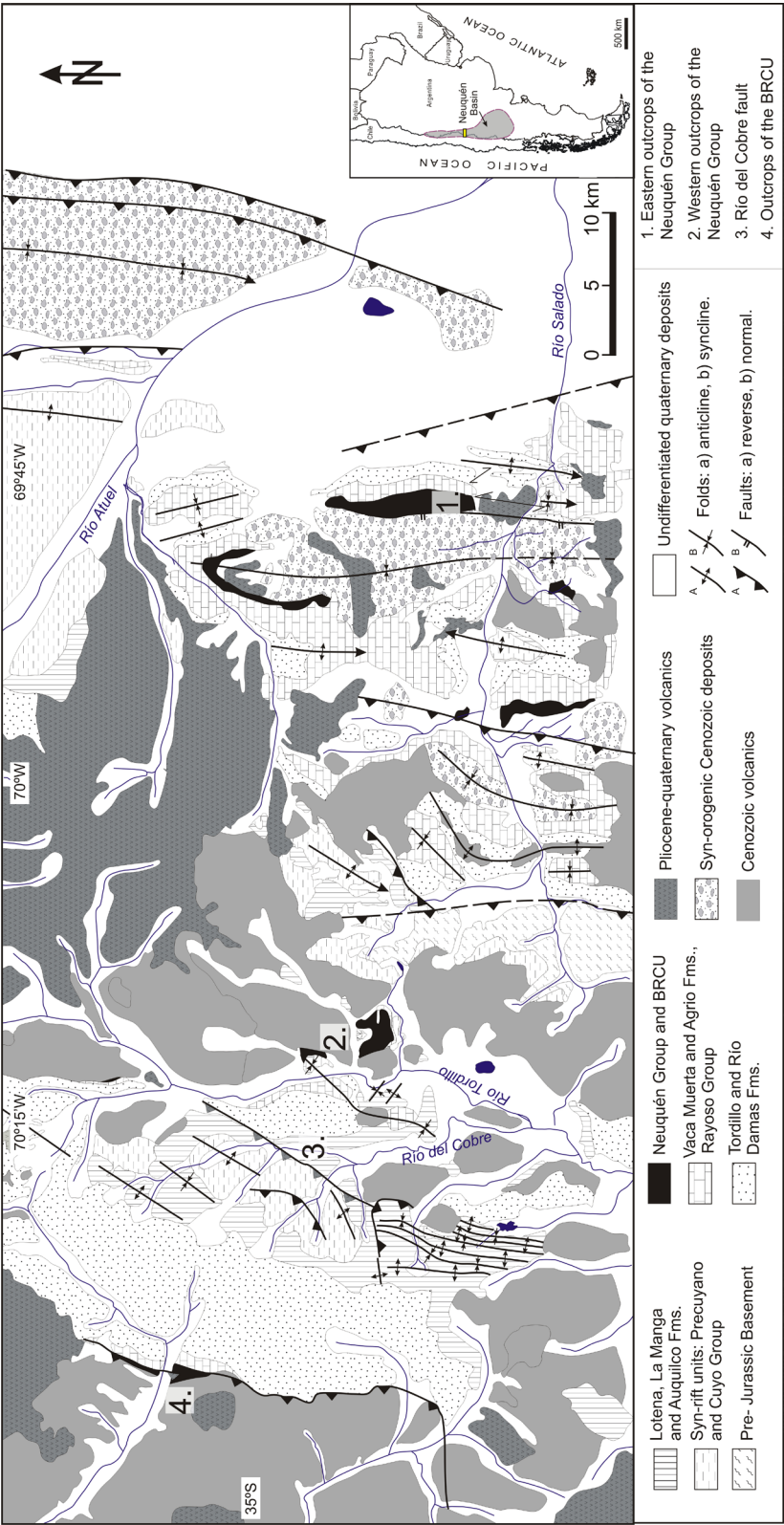


FIG. 3. Simplified geologic map of the Andes at 35°S, based on Mescua (2011). The rectangle in the inset shows the location of the study area, in the northern part of the Neuquén basin. Outcrops of the Neuquén Group and BRCU are shown in black. The numbers indicate the main localities mentioned in the text: 1. Eastern outcrops of the Neuquén Group; 2. Western outcrops of the Neuquén Group in Portezuelo Ancho; 3. Río del Cobre fault; 4. Outcrops of the BRCU in Termas del Flaco.

A western sector of outcrops is located in the area of the classic geological locality of Portezuelo Ancho, where a partial column of 350 m of the lower part of the unit is found (Legarreta and Kozlowski, 1984); while the top of the Neuquén Group was eroded. The succession corresponds to an upward-finishing package, with grey sandstones and conglomerates in the base which grade upwards to red sandstones and shales. The eastern outcrops are found in the easternmost Malargüe fold-and-thrust belt, near the Cenozoic orogenic front. Most of this sector is covered by Quaternary lavas and alluvial and colluvial deposits, and the Neuquén Group is poorly exposed, with isolated patches of red sandstones (Dajczgewand, 2002).

The base of the succession of the Neuquén Group in the western outcrops, as observed 3 km north of Portezuelo Ancho, is composed by 150 m of grey

conglomerates. The beds are lenticular, 1 to 3 m thick, and the conglomerates are clast-supported, with sub-rounded clasts of up to 30 cm (Fig. 4a). Clast composition is polymictic (Fig. 4b): andesites predominate, and red sandstones and limestones are also abundant. This suggests a provenance from the Late Jurassic and Cretaceous units which were deposited in this sector of the Neuquén basin. In particular, andesites are one of the dominant lithologies of the Kimmeridgian Río Damas Formation, limestones are derived from the marine rocks of the Tithonian to Hauterivian Mendoza Group, and red sandstones are interpreted to be derived from the Kimmeridgian Tordillo Formation or from the erosion of older deposits from the same Neuquén Group. The succession grades to a sandstone predominant section, composed of 1 m-thick lenticular beds of red sandstones with through cross-bedding,

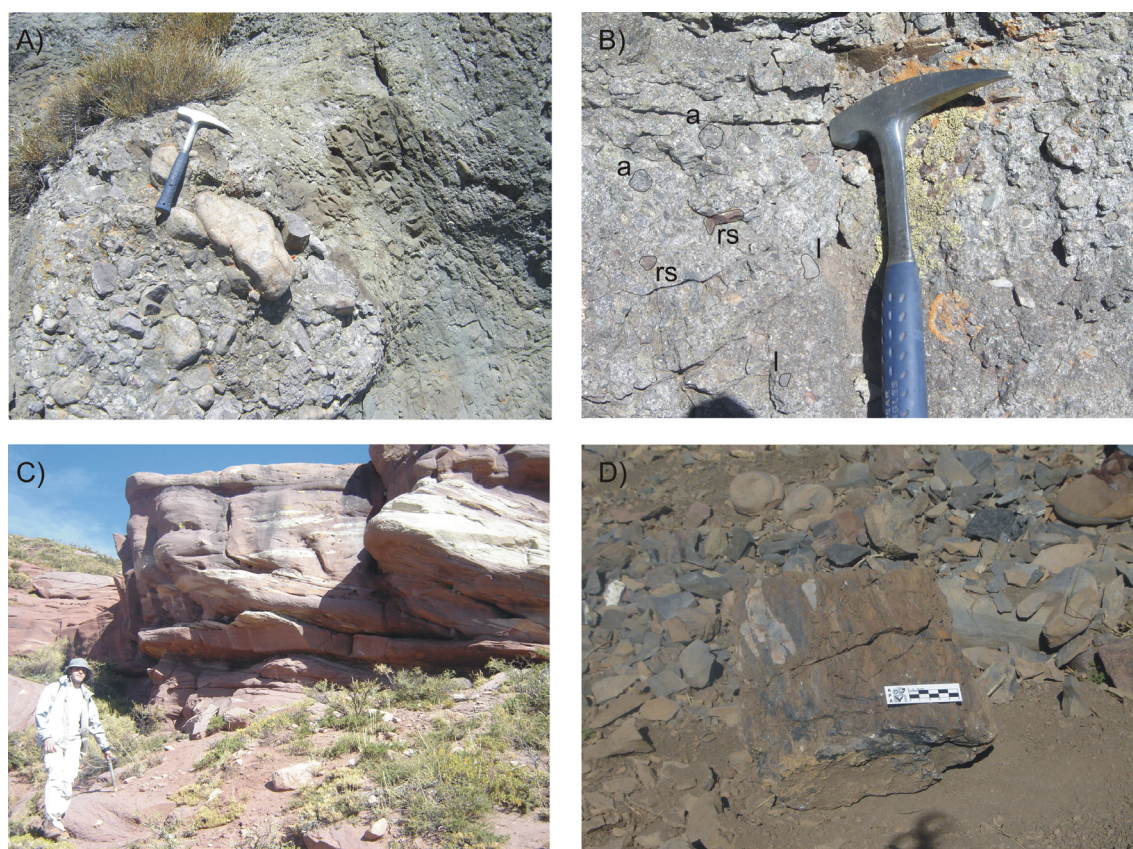


FIG. 4. **A)** Conglomerates of the base of the Neuquén Group in the western sector of outcrops. Note the large size of the clasts, hammer for scale. **B)** Detail of a bed of conglomerate, showing the polymictic composition of the clasts. References: **a**: andesite; **rs**: red sandstone; **l**: limestone. **C)** Red sandstones of the middle Neuquén Group. **D)** Trunk from the fine-grained upper section of the Neuquén Group (the photograph shows a fallen specimen, not in place).

parallel lamination and climbing ripples (Fig. 4c). Shale content increases upwards, giving place to a section composed by red shales which contains fossilized trunks of 30 cm of diameter (Fig. 4d).

In Portezuelo Ancho, the succession has been described by Legarreta and Kozłowski (1984). The fining-upward tendency is also observed in this locality, though conglomerates in the base are slightly finer (maximum clast size is 20 cm), and clasts of fossiliferous limestones of the Mendoza Group are dominant.

Therefore, the composition of the clasts of the conglomerates indicates the exhumation and erosion of the Late Jurassic and Early Cretaceous units of the Neuquén basin.

The eastern outcrops of the Neuquén Group correspond to a much finer grained succession, composed by red sandstones and minor intercalations of gravelly sandstones. Dajczgiewand (2002) characterized these sandstones as derived from a clastic source of pre-Jurassic basement located towards the east. South of 36°S, Di Giulio *et al.* (2010) applied U-Pb dating of detrital zircons in the eastern outcrops of the Neuquén Group, and also observed a basement clastic source, which they interpreted as the result of the erosion of a peripheral bulge located further east. The eastern outcrops at 35°S confirm this interpretation.

5. The Brownish-Red Clastic Unit and the Mesozoic-Cenozoic unconformity in Chile

The Brownish-Red Clastic Unit (BRCU) was defined by Charrier *et al.* (1996) in the locality of Termas del Flaco in Chile (marked as 4 in figure 3). It corresponds to a succession of continental rocks with a thickness of 250 m, composed of a basal breccia, conglomerates and sandstones showing an upward-fining arrangement. It is covered unconformably by volcanic and volcanoclastic deposits of the Late Eocene-Miocene Abanico Formation (Charrier *et al.*, 1996; Flynn *et al.*, 2003). Charrier *et al.* (1996) suggest a correlation with the Neuquén Group based on the lithological characteristics of both units and the finding of dinosaur remains in the BRCU which constrain its age to the Cretaceous. U-Pb dating of detrital zircons from this unit provided ages around 90 Ma (80–118 Ma, Aguirre *et al.*, 2009), which indicate a Late Cretaceous maximum age for this unit. Our observations in the Portezuelo Ancho area support the correlation with the Neuquén Group, since the lithological characteristics, the upward-fining

sedimentary pattern and the stratigraphic position of the Neuquén Group in that area are similar to those of the BRCU. Furthermore, Charrier *et al.* (1996) state that ‘the coarse basal breccia of the BRCU is difficult to account for in the context of any simple regression model. Irrespective of the true correlations involved, faulting along the basin margin must have contributed to the abrupt transition observed’. This agrees with the hypothesis of a Cretaceous deformation event and therefore the BRCU is interpreted as deposited when thrusting was taking place west of the present locality of Termas del Flaco. It should be noted, however, that zircon fission track dating of samples from the BRCU was carried out by Waite (2005), obtaining ages between 90.5 ± 10.9 and 62.8 ± 5.4 Ma. The younger ages indicate a Paleocene minimum age for deposition of part of the BRCU, which suggests that: *i.* the BRCU deposited over a longer timespan than the Neuquén Group, and *ii.* that the Cretaceous deformation in the Termas del Flaco area might have extended into the Paleogene.

The unconformity between the Mesozoic units (Baños del Flaco Formation and BRCU) and the Late Eocene to Miocene Abanico Formation is of only a few degrees in the Termas del Flaco area (Charrier *et al.*, 1996). It is remarkable, however, that in less than 2 km of distance, the Abanico Formation presents different stratigraphic relations: it covers the BRCU in the northern sector of the area, and the Baños del Flaco Formation towards the south (Fig. 5). This implies that the 250 m of thickness of the BRCU were eroded prior to the late Eocene in this last sector - or that this unit was not deposited, which seems unlikely given the short distance. Based on the information presented in the previous sections, we conclude that the erosional event is related to the Late Cretaceous to Paleogene activity of a fault located to the east of the Termas del Flaco locality, the Río del Cobre fault (indicated in figure 3), which could have generated a large anticline with harpoon geometry (McClay, 1995). Erosion of part of the the BRCU might have taken place in part of the low-dipping backlimb of the anticline, whereas erosion of the frontal limb of the anticline provided the sediments which were deposited in the Portezuelo Ancho area (Fig. 6). It is worth noting that the sector where the BRCU was eroded corresponds to the location of maximum displacement of the Río del Cobre fault, and that the reverse throw of this structure decreases rapidly to the north (Mescua, 2011), coincidently with

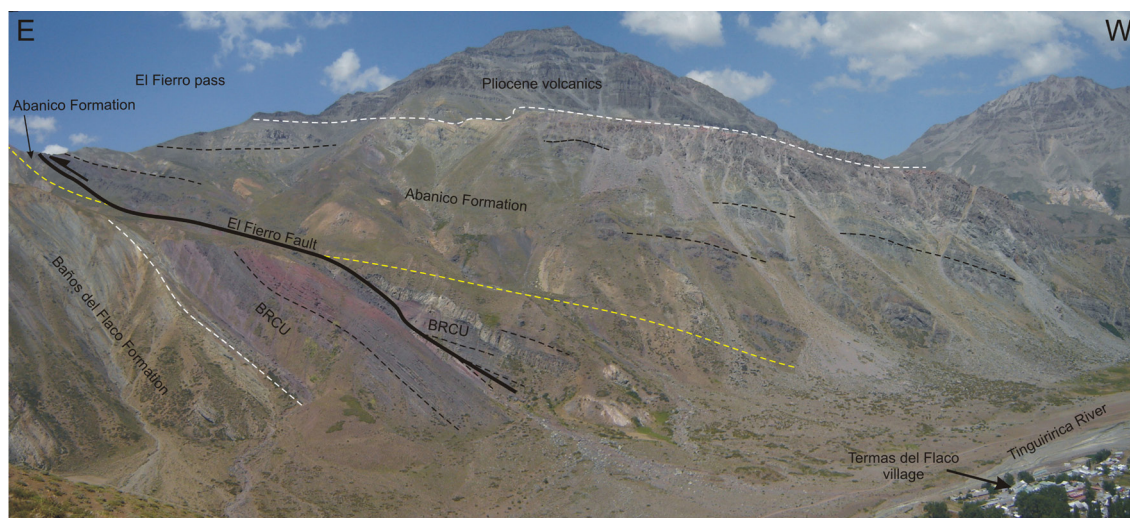


FIG. 5. Outcrops of the BRCU at Termas del Flaco. Note the contact between the Cenozoic Abanico Formation and the Mesozoic units (discontinuous grey line): in the northern sector, nearest the valley, the Abanico Formation covers the BRCU, whereas to the south, close to the El Fierro pass, it covers the Baños del Flaco Formation. The El Fierro fault is a Miocene structure (post-Abanico).

the preservation of the BRCU in the backlimb of the anticline. In Oligocene times, the extensional Abanico basin was developed, and deposition of the Abanico Formation preserved the erosional surface carved on the Mesozoic rocks. Since the Miocene, the compressional deformation of the Abanico basin took place, and the generation of the El Fierro fault resulted in the complex geometry observed at present (Fig. 5).

6. Discussion and conclusions

Our results are consistent with the interpretation of the Neuquén Group as foreland basin deposits. An important relief contrast between the clastic source area and the basin, as well as a short distance of transport, is needed to provide large clasts (diameters of 30 cm) as those found in the basal conglomerates at Portezuelo Ancho. Furthermore, clast compositions indicate the exhumation of Late Jurassic and Early Cretaceous units. The regional geometry of the Neuquén Group, without abrupt thickness changes or evidence of syn-sedimentary faulting, and with uniformly spaced isopach trends in the Neuquén embayment (Legarreta and Uliana, 1998) prevents the interpretation of the basin as extensionally controlled in the period of deposition of this unit. Therefore our interpretation is that the Neuquén Group deposited at 35°S in a foreland basin setting, during a Late

Cretaceous phase of compressional deformation, in agreement with other work focused south of this latitude (Tunik *et al.*, 2010; Di Giulio *et al.*, 2010). The Cretaceous orogenic front at this latitude can be related to the Río del Cobre fault, located 5 km to the west of the outcrops of the Neuquén Group at Portezuelo Ancho (Fig. 3). This structure is a Jurassic normal fault which was inverted during Andean compression, as indicated by thickness and facies changes of the Jurassic units at both sides of the structure. Age constraints for Andean tectonics east of the Portezuelo Ancho area suggest a beginning of deformation in the Middle Miocene (Combina and Nullo, 1997, 2011; Mescua, 2011). Our data suggest that the Río del Cobre fault was inverted in the Late Cretaceous and probably again in the Paleogene. The reactivation of the same structure in the Miocene makes it difficult to estimate the Cretaceous displacement. The Neuquén Group conglomerates include clasts of the Río Damas Formation. The exhumation of this unit requires the previous exposure of the 150 m of overlying Lower Cretaceous rocks, which can be taken as a minimum Late Cretaceous displacement. The great thickness of the partially exhumed Río Damas Formation (between 3,000 and 5,000 m, Kohn, 1960) prevents an accurate estimation of the pre-Miocene displacement, which could be as much as 5,000 m. However, an important Miocene reactivation of this structure can be inferred from the present structural

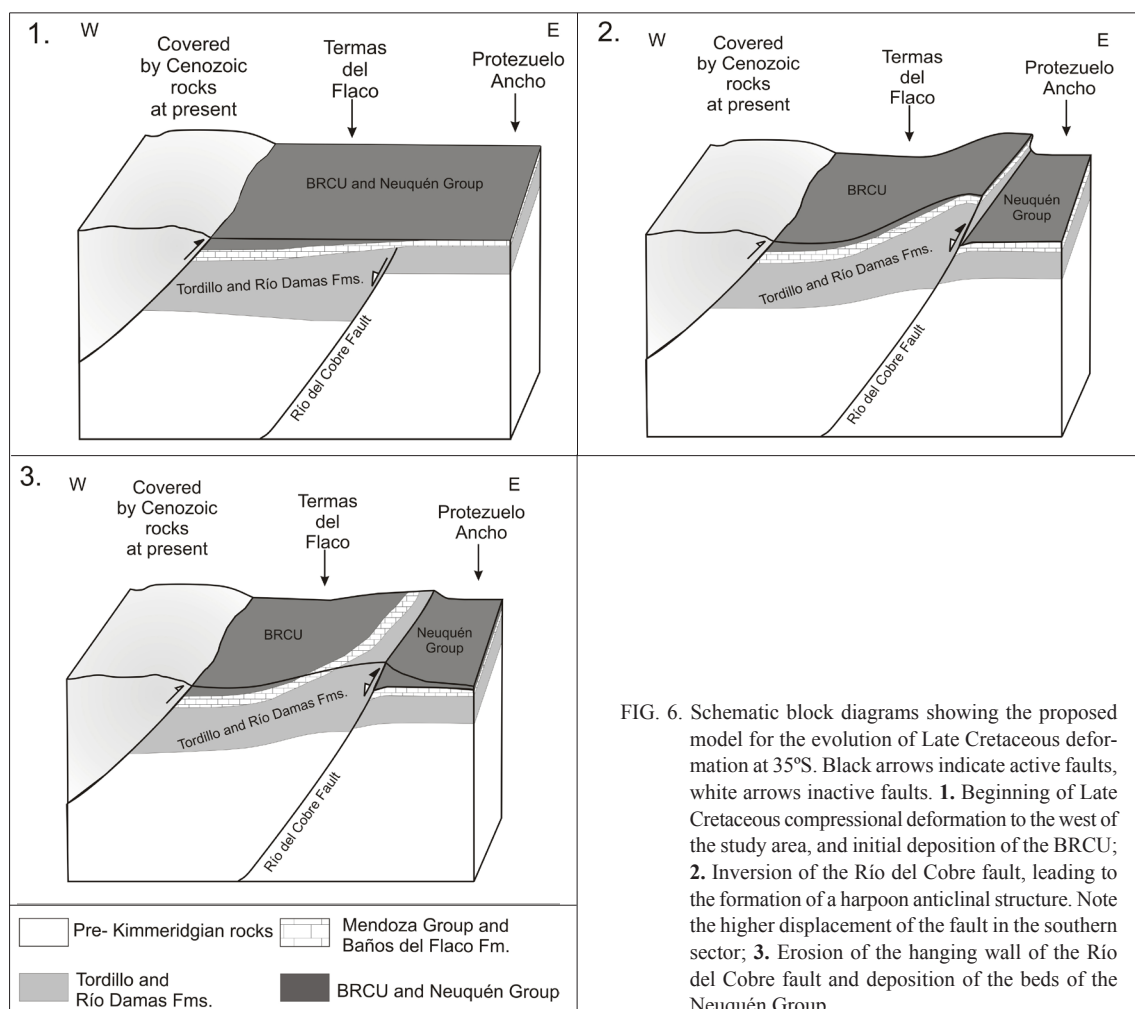


FIG. 6. Schematic block diagrams showing the proposed model for the evolution of Late Cretaceous deformation at 35°S. Black arrows indicate active faults, white arrows inactive faults. **1.** Beginning of Late Cretaceous compressional deformation to the west of the study area, and initial deposition of the BRCU; **2.** Inversion of the Río del Cobre fault, leading to the formation of a harpoon anticlinal structure. Note the higher displacement of the fault in the southern sector; **3.** Erosion of the hanging wall of the Río del Cobre fault and deposition of the beds of the Neuquén Group.

relations (Mescua, 2011), which suggests that the Late Cretaceous displacement was not that large.

The local characteristics of the structure in this part of the Andes, which corresponds to the inversion of the Río del Cobre fault and the formation of an anticline with a harpoon geometry, have resulted in a low angle unconformity between the Mesozoic strata and Cenozoic rocks in the backlimb of the anticline. In spite of this low angle, in part of the study area at least 250 m of the BRCU were eroded before the deposition of the Abanico Formation in the Oligocene-Miocene. South of the study area, the contact between the Mesozoic beds and the Abanico Formation is covered by Pliocene and Quaternary volcanic rocks. If the Late Cretaceous compressional phase of deformation extended further north, as proposed by Orts and Ramos (2006), the

unconformity between the Mesozoic strata and the Abanico Formation (and equivalent units) should be a major feature of the Andes in its western slope, where Oligocene and Early Miocene units were deposited. At the Cachapual River (34°20'S), an important unconformity was proposed by Charrier (1973, 1982) and Charrier *et al.* (2002). In contrast, Godoy (1991) and Godoy *et al.* (1999) interpreted the contact as tectonic. Further complications arise from the difficulty in differentiating the Cretaceous and Cenozoic units in this sector of the Andes, since lithologically, units of both ages are very similar. Future investigations are needed to verify if the Mesozoic-Cenozoic (pre-Miocene) unconformity can be recognized at a regional scale.

Figure 7 shows the extent of Late Cretaceous deformation recognized in the Southern Central

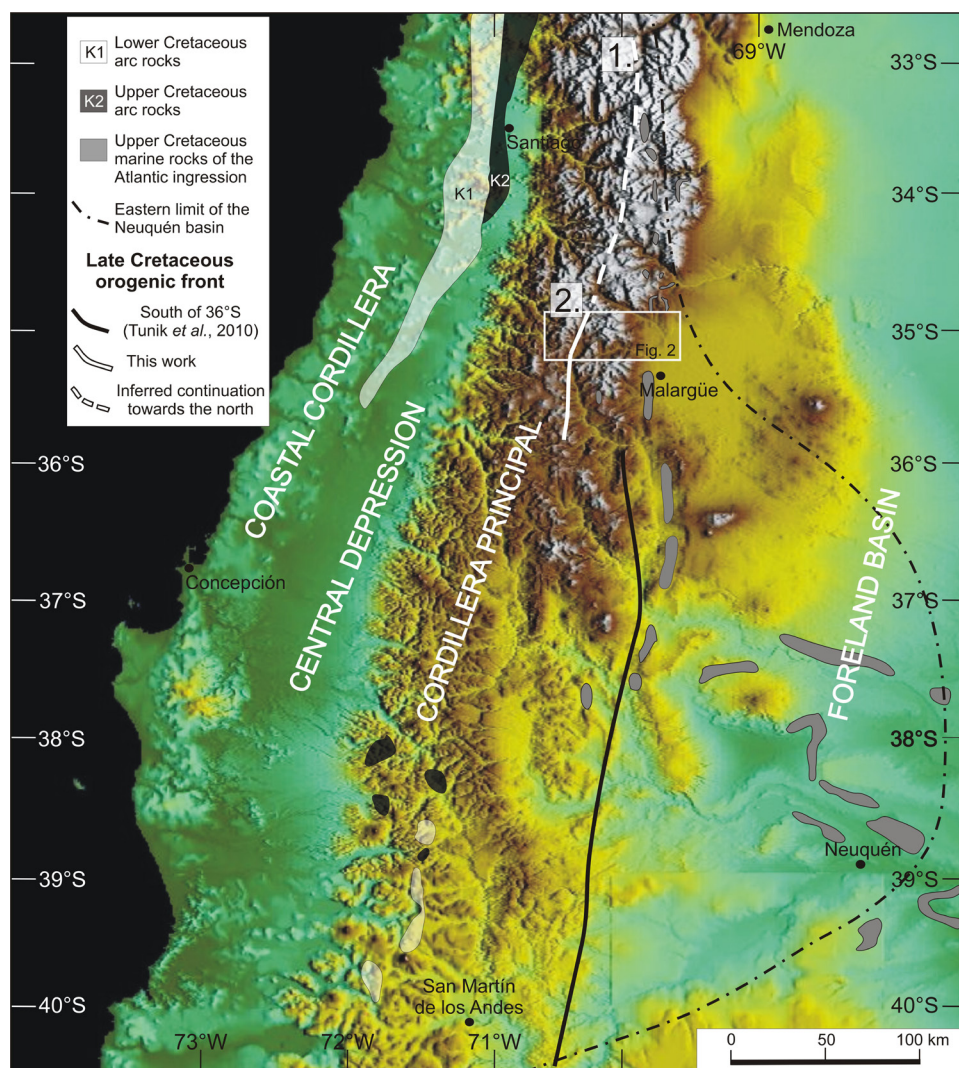


FIG. 7. Extent of the Late Cretaceous orogenic deformation between 33° and 39°S. Base image is the GTOPO30 digital elevation model. The orogenic front south of 36°S is drawn according to Tunik *et al.* (2010). Also shown are: the Lower Cretaceous (K1) and Upper Cretaceous (K2) magmatic arc rocks (according to the Geologic Map of Chile, SERNAGEOMIN, 2003), and the Upper Cretaceous marine deposits of the first Atlantic Ingression (based on Tunik, 2003; Sruoga *et al.*, 2005; Aguirre-Urreta *et al.*, 2010; Pose *et al.*, 2011). Note the displacement of the orogenic front to the west from 35°S northwards. 1. Río del Plomo locality, where Orts and Ramos (2006) have described syn-orogenic unconformities in beds of the Neuquén Group. 2. Río del Cobre fault, which concentrated the deformation in the Late Cretaceous orogenic front at 35°S and the first stage of the compressional Miocene to recent phase at the same latitude. The white box shows the location of figure 2.

Andes between 33°S and 39°S. We have extended the orogenic front towards the north of the study area based on a compilation of the scarce information available. The description of syn-tectonic unconformities in beds of the Neuquén Group in the Río del Plomo area (Orts and Ramos, 2006) is the only known evidence of Late Cretaceous deformation for

this northern region. On the other hand, the presence of marine Maastrichtian deposits resulting from an Atlantic Ingression in some sectors of the high Andes of Mendoza (Tunik, 2003; Pose *et al.*, 2011) can be taken as indicative of areas which were part of the foredeep of the foreland basin (Aguirre-Urreta *et al.*, 2011), and therefore not uplifted in the Late

Cretaceous, which allows to outline the approximate location of the orogenic front.

The data available so far indicates an important change in the location of the orogenic front. The orogenic front south of 36°S is located 40 km to the east of the orogenic front north of 35°S. At the longitude of 69°45'W, Late Cretaceous structures have been identified in the south, while in the north the Maastrichtian deposits of the marine ingression indicate an area that was not uplifted.

It is important to mention that this sector of the Andes also presents particular characteristics during its Cenozoic evolution. Anomalous low values of shortening and crustal thickness at 35°S (Giambiagi *et al.*, 2012), and changes in exhumation amounts north and south of this latitude (Spikings *et al.*, 2008) have been reported for the post-Miocene Andean history.

Therefore, the change in the location of the orogenic front observed for the Late Cretaceous orogenic event suggests that this sector has been a long-lived transitional area separating zones of different behaviour in the Andean orogen. It is particularly noteworthy that this latitude also coincides with the change between the narrow basin of the northern sector and the wider southern embayment of the Neuquén basin (Fig. 1). Furthermore, the change in the infill of the Triassic-Early Jurassic extensional depocenters of the Neuquén basin, from a sedimentary infill in the north to a volcanic and volcanoclastic infill in the south, indicates a transition between passive and active rifting behaviors. This contrast can have a long-standing effect on the composition and strength of the crust, which can influence the post-Mesozoic geologic history, and be reflected in variations in the behavior of the segments north and south of 35°S during the Andean orogeny.

As a final remark, it should be mentioned that the widespread recognition throughout the Andes of a Late Cretaceous start of the compressional deformation suggests that the initiation of the Andean orogeny was related to global or at least continental-scale processes. A link between the initiation of compressional tectonics in the Andes and the final disconnection between South America and Africa during the opening of the South Atlantic ocean has been proposed by several authors (*e.g.*, Mpodozis and Ramos, 1989; Jaillard *et al.*, 2000). Furthermore, according to Somoza and Zaffarana (2008), the change from extensional to compressional

conditions in the present Andean region would be related to a global plate reorganization which took place in the Mid-Cretaceous and resulted in an increase in the westward drift of South America since Late Cretaceous times. The scenario which arises from investigations across the whole Andean range supports this hypothesis.

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References

- Aguirre, L.; Calderón, S.; Vergara, M.; Oliveros, V.; Morata, D.; Belmar, M. 2009. Edades isotópicas de rocas de los valles Volcán y Tinguiririca, Chile central. In Congreso Geológico Chileno, No. 12, Servicio Nacional de Geología y Minería, Actas S8-001 (digital): 4 p. Santiago.
- Aguirre-Urreta, B.; Tunik, M.; Naipauer, M.; Pazos, P.; Ottone, G.; Fanning, M.; Ramos, V.A. 2011. Malargüe Group (Maastrichtian-Danian) deposits in the Neuquén Andes, Argentina: Implications for the onset of the first Atlantic transgression related to Western Gondwana break-up. *Gondwana Research* 19 (2): 482-494.
- Armas, P.; Sánchez, M.L. 2011. Análisis estratigráfico secuencial de las formaciones Anacleto y Allen (Cretácico Tardío) en el borde nororiental de Cuenca Neuquina, Argentina. *Andean Geology* 38 (1): 119-155.
- Aspden, J.A.; Harrison, S.H.; Rundle, C.C. 1992. New geochronological control for the tectono-magmatic evolution of the metamorphic basement, Cordillera Real and El Oro province of Ecuador. *Journal of South American Earth Sciences* 6: 77-96.
- Aubouin, J.A.; Borrello, A.V.; Cecioni, G.; Charrier, R.; Chotin, P.; Frutos, J.; Thiele, R.; Vicente, J.C. 1973. Esquisse paleogeographique et structurale des Andes Meridionales. *Revue de Geographie Physique et de Geologie Dynamique* 15 (1-2): 11-71.
- Barrio, C.A. 1990. Late Cretaceous-Early Tertiary sedimentation in a semi-arid foreland basin (Neuquén Basin, western Argentina). *Sedimentary Geology* 66: 255-275.

- Bechis, F.; Giambiagi, L.; García, V.; Lanés, S.; Cristallini, E.; Tunik, M. 2010. Kinematic analysis of a transtensional fault system: the Atuel depocentre of the Neuquén basin, Central Andes, Argentina. *Journal of Structural Geology* 32: 886-899.
- Biddle, K.T.; Uliana, M.; Mitchum, M.; Fitzgerald, M.; Wright, R. 1986. The stratigraphic and structural evolution of the central and eastern magallanes basin, southern South America. In *Foreland Basins* (Allen, P.A.; Homewood, P.; editors). International Association of Sedimentologists. Special Publication 8: 41-61.
- Blakey, R. 2010. Late Early Cretaceous Mollewide Paleogeographic map. Available at <http://cpgeosystems.com/mollglobe.html> (accessed 13/6/2011).
- Cazau, L.B.; Uliana, M.A. 1973. El Cretácico Superior continental de la cuenca Neuquina. In *Congreso Geológico Argentino*, No. 5, Actas 3: 131-163. Buenos Aires.
- Charrier, R. 1973. Geología de las provincias O'Higgins y Colchagua. Instituto de Investigaciones de Recursos Naturales (IREN). Publicación, No. 7: 69 p. Santiago.
- Charrier, R. 1982. La Formación Leñas-Espinoza: Redefinición, petrografía y ambiente de sedimentación. *Revista Geológica de Chile* 17: 71-82.
- Charrier, R.; Wyss, A.R.; Flynn, J.J.; Swisher, C.; Norell, M.A.; Zapata, F.; McKenna, M.C.; Novacek, M.J. 1996. New evidence for Late Mesozoic-Early Cenozoic evolution of the Chilean Andes in the Upper Tinguiririca Valley (35°S), Central Chile. *Journal of South American Earth Sciences* 9: 393-422.
- Charrier, R.; Baeza, O.; Elgueta, S.; Flynn, J.J.; Gans, P.; Kay, S.M.; Munoz, N.; Wyss, A.R.; Zurita, E. 2002. Evidence for Cenozoic extensional basin development and tectonic inversion south of the flat-slab segment, southern Central Andes, Chile (33°-36°S). *Journal of South American Earth Sciences* 15: 117-139.
- Cobbold, P.R.; Rossello, E.A. 2003. Aptian to recent compressional deformation of the Neuquén Basin, Argentina. *Marine and Petroleum Geology* 20: 429-443.
- Combina, M.; Nullo, F. 1997. Consideraciones tectosedimentarias sobre la Formación Río Diamante, Cordillera de los Andes. *Cuadernos de Geología Ibérica*, 22: 305-320.
- Combina, M.; Nullo, F. 2011. Ciclos tectónicos, volcánicos y sedimentarios del Cenozoico del sur de Mendoza-Argentina (35°-37°S y 69°30'W). *Andean Geology* 38 (1): 198-218.
- Corbella, H.; Novas, F.E.; Apesteguía, S.; Leanza, H.A.; 2004. First fission-track age for the dinosaur-bearing Neuquén Group (Upper Cretaceous), Neuquén Basin, Argentina. *Revista del Museo Nacional de Ciencias Naturales* 6 (2): 227-232.
- Cristallini, E.; Tomezzoli, R.; Pando, G.; Gazzera, C.; Martínez, J.M.; Quiroga, J.; Buhler, M.; Bechis, F.; Barredo, S.; Zambrano, O. 2009. Controles precuianos en la estructura de la cuenca Neuquina. *Revista de la Asociación Geológica Argentina* 65 (2): 248-264.
- Cruz, C.E.; Condat, P.; Kozłowski, E.; Manceda, R. 1989. Análisis estratigráfico secuencial del Grupo Neuquén (Cretácico superior) en el valle del río Grande, provincia de Mendoza. In *Congreso Nacional de Exploración de Hidrocarburos*, No. 1, Actas 2: 689-714. Mar del Plata.
- Dajczgiewand, D.M. 2002. Faja Plegada y Corrida de Malargüe: estilo de la deformación en Mallín Largo. Trabajo Final de Licenciatura (Unpublished), Universidad de Buenos Aires, Facultad de Ciencias Exactas y Naturales, Departamento de Geología: 119 pp.
- Dewey, J.F.; Bird, J.M. 1970. Mountain Belts and the New Global Tectonics. *Journal of Geophysical Research* 75: 2625-2647.
- Digregorio, J.H. 1972. Neuquén. In *Geología Regional Argentina* (Leanza, A.F.; editor). Academia Nacional de Ciencias: 439-505. Córdoba.
- Di Giulio, A.; Ronchi, A.; Sanfilippo, A.; Tiepolo, M.; Ramos, V.A. 2010. Cretaceous evolution of the Neuquén basin recorded by U-Pb ages of detrital zircons. In *International Sedimentological Congress*, No 18, Abstracts Volume: p. 301, Mendoza.
- Fildani, A.; Cope, T.D.; Graham, S.A.; Wooden, J.L. 2003. Initiation of the Magallanes foreland basin: timing of the southernmost Patagonian Andes orogeny revised by detrital zircon provenance analysis. *Geology* 31: 1081-1084.
- Flynn, J.J.; Wyss, A.R.; Croft, D.A.; Charrier, R. 2003. The Tinguiririca Fauna, Chile: biochronology, paleoecology, biogeography, and a new earliest Oligocene South American Land Mammal 'Age'. *Palaeogeography, Palaeoclimatology, Palaeoecology* 195 (3-4): 229-259.
- Gerth, E. 1925. Estratigrafía y distribución de los sedimentos mesozoicos en los Andes argentinos. *Academia Nacional de Ciencias*, Actas 9 (1): 11-55. Córdoba.
- Gerth, E. 1931. La estructura geológica de la Cordillera argentina entre el río Grande y río Diamante en el sur de la provincia de Mendoza. *Academia Nacional de Ciencias*, Actas 10 (2): 125-172. Córdoba.
- Giambiagi, L.B.; Bechis, F.; Garcia, V.; Clark, A. 2008. Temporal and spatial relationships of thick- and thin-skinned deformation: A case study from the Malargüe

- fold-and-thrust belt, southern Central Andes. *Tectonophysics* 459: 123-139. doi:10.1016/j.tecto.2007.11.069
- Giambiagi, L.B.; Tunik, M.; Barredo, S.; Bechis, F.; Ghiglione, M.; Álvarez, P.; Drosina, M. 2009. Cinemática de apertura del sector norte de la cuenca Neuquina. *Revista de la Asociación Geológica Argentina* 65 (1): 140-153.
- Giambiagi, L.; Mescua, J.F.; Bechis, F.; Tassara, A.; Hoke, G. 2012. Thrust belts of the Southern Central Andes: along-strike variations in shortening, topography, crustal geometry, and denudation. *Geological Society of America Bulletin* 124: 1339-1351.
- Godoy, E. 1991. El Corrimiento del Fierro reemplaza a la discordancia intrasenoniana en el río Cachapoal, Chile Central. *In* Congreso Geológico Chileno, No. 6, Actas: 635-639. Viña del Mar.
- Godoy, E.; Yáñez, G.; Vera, E. 1999. Inversion of an Oligocene volcano-tectonic basin and uplifting of its superimposed Miocene magmatic arc in the Chilean Central Andes: first seismic and gravity evidences. *Tectonophysics* 306: 217-236.
- Groeber, P. 1929. Líneas fundamentales de la geología del Neuquén, sur de Mendoza y regiones adyacentes. Dirección General de Minas, Geología e Hidrología, Ministerio de Agricultura, Publicación 58: 1-10. Buenos Aires.
- Gulisano, C.A.; Gutiérrez Pleimling, A.R. 1994. The Jurassic of the Neuquén Basin: Mendoza Province. *Asociación Geológica Argentina, Field Guide, Special Publication* 159: 103 p. Buenos Aires.
- Jaillard, E.; Héral, G.; Monfret, T.; Díaz-Martínez, E.; Baby, P.; Lavenue, A.; Dumont, J.F. 2000. Tectonic evolution of the Andes of Ecuador, Perú, Bolivia and northernmost Chile. *In* Tectonic Evolution of South America (Cordani, U.G.; Milani, E.J.; Thomaz Filho, A.; Campos, D.A.; editors). *International Geological Congress*, No. 31: 481-559. Río de Janeiro.
- Jaimes, E.; de Freitas, M. 2006. An Albion-Cenomanian unconformity in the northern Andes: evidence and tectonic significance. *Journal of South American Earth Sciences* 21: 466-492.
- Jordan, T.E.; Isacks, B.L.; Allmendinger, R.W.; Brewer, J.A.; Ramos, V.A.; Ando, C.J. 1983. Andean tectonics related to geometry of subducted Nazca plate. *Geological Society of America Bulletin* 94: 341-361.
- Keidel, J. 1925. Sobre la estructura tectónica de las capas petrolíferas en el oriente del Territorio del Neuquén. Ministerio de Agricultura, Dirección General de Minas, Geología e Hidrología, Publicaciones 8: 1-67. Buenos Aires.
- Klohn, C. 1960. Geología de la Cordillera de los Andes de Chile Central, Provincias de Santiago, O'Higgins, Colchagua y Curicó. *Investigaciones Geológicas, Boletín*, No. 8: 95 p. Santiago, Chile.
- Kozłowski, E.; Mancada, R.; Ramos, V.A. 1993. Estructura. *In* Geología y Recursos Naturales de Mendoza (Ramos, V.A.; editor). *Congreso Geológico Argentino*, No. 12 y Congreso de Exploración de Hidrocarburos, No. 2, Relatorio: 235-256. Buenos Aires.
- Lanés, S.; Giambiagi, L.B.; Bechis, F.; Tunik, M. 2008. Late Tertiary-Early Jurassic successions of the Atuel Depocenter: sequence stratigraphy and tectonic controls. *Revista de la Asociación Geológica Argentina*, 63 (4): 534-548.
- Leanza, H.A. 2009. Las principales discordancias del Mesozoico de la cuenca Neuquina según observaciones de superficie. *Revista del Museo Nacional de Ciencias Naturales* 11 (2): 145-184.
- Legarreta, L.; Kozłowski, E. 1984. Secciones condensadas del Jurásico-Cretácico de los Andes del sur de Mendoza: estratigrafía y significado tectosedimentario. *In* Congreso Geológico Argentino, No. 9, Actas 1: 286-297. Bariloche.
- Legarreta, L.; Gulisano, C.A. 1989. Análisis estratigráfico secuencial de la cuenca Neuquina (Triásico superior-Terciario inferior). *In* Cuencas Sedimentarias Argentinas (Chebli, G.; Spalletti, L.; editors). Universidad Nacional de Tucumán, Facultad de Ciencias Naturales, Correlación Geológica Serie 6: 221-243. Tucumán.
- Legarreta, L.; Uliana, M.A. 1996. The Jurassic succession in west-central Argentina: stratal patterns, sequences and paleogeographic evolution. *Palaeogeography, Palaeoclimatology, Palaeoecology* 120: 303-330.
- Legarreta, L.; Uliana, M.A. 1998. Anatomy of hinterland depositional sequences: Upper Cretaceous fluvial strata, Neuquén basin, west-central Argentina. *In* Relative role of Eustasy, Climate, and Tectonism in Continental Rocks (Shanley, K.W.; McCabe, P.J.; editors). *Society for Sedimentary Geology (SEPM) Special Publication* 59: 83-92.
- Legarreta, L.; Uliana, M.A. 1999. El Jurásico y Cretácico de la Cordillera Principal y la cuenca Neuquina. 1. Facies sedimentarias. *In* Geología Argentina (Camino, R.; editor). Servicio Geológico y Minero Argentino, Instituto de Geología y Recursos Minerales, *Anales* 29 (16): 399-416. Buenos Aires.
- Mancada, R.; Figueroa, D. 1995. Inversion of the Mesozoic Neuquén rift in the Malargüe fold-thrust belt,

- Mendoza, Argentina. In *Petroleum Basins of South America* (Tankard, A.J.; Suárez, R.; Welsink, H.J.; editors). American Association of Petroleum Geology, Memoir 62: 369-382.
- Martin-Gombojav, N.; Winkler, W. 2008. Recycling of Proterozoic crust in the Andean Amazon foreland of Ecuador: implications for orogenic development of the Northern Andes. *Terra Nova* 20: 22-31.
- McClay, K.R. 1995. The geometries and kinematics of inverted fault systems: a review of analogue model studies. In *Basin inversion* (Buchanan, J.G.; Buchanan P.G.; editors). Geological Society of London, Special Publication 88: 97-118.
- Mégard, F. 1984. The Andean orogenic period and its major structures in central and northern Peru. *Journal of the Geological Society* 141: 893-900.
- Mescua, J.F. 2011. Evolución estructural de la Cordillera Principal entre Las Choicas y Santa Elena (35°S), Provincia de Mendoza, Argentina. Ph.D. Thesis (Unpublished), Universidad de Buenos Aires: 244 p.
- Mpodozis, C.; Ramos, V.A. 1989. The Andes of Chile and Argentina. In *Geology of the Andes and Its Relation to Energy and Mineral Resources* (Ericksen, G.E.; Cañas Pinochetand, M.T.; Reinemund, J.A.; editors). Circum-Pacific Council for Energy and Mineral Resources, Earth Sciences Series 14: 59-90. Houston.
- Muller, R.D.; Sdrolias, M.; Gaina, C.; Steinberger, B.; Heine, C. 2008. Long-term sea level fluctuations driven by ocean basin dynamics. *Science* 319: 1357-1362.
- Oncken, O.; Chong, G.; Franz, G.; Giese, P.; Götze, H.-J.; Ramos, V.A.; Strecker, M.R.; Wigger, P. (editors). 2006. *The Andes - Active subduction orogeny*. Springer Frontiers in Earth Sciences Series: 592 p. Berlin.
- Orts, S.; Ramos, V.A. 2006. Evidence of Middle to Late Cretaceous compressive deformation in the High Andes of Mendoza, Argentina. *Backbone of the Americas Meeting, Abstracts with Programs* 5: p. 65. Mendoza.
- Pose, F.; Folguera, A.; Ramos, V.A. 2011. Geología regional del sector interno de los Andes en las nacientes del río Barrancas, provincias de Mendoza y Neuquén. In *Congreso Geológico Argentino*, No. 18, Actas: 827-828. Neuquén, Argentina.
- Ramos, V.A. 1988. The tectonics of the Central Andes: 30° a 33°S latitude. In *Processes in continental lithospheric deformation* (Clark, S.; Burchfield, D.; editors). Geological Society of America, Special Papers 218:31-54.
- Ramos, V.A. 1999. Plate tectonic setting of the Andean cordillera. *Episodes* 22 (3): 183-190.
- Ramos, V.A.; Folguera, A. 2005. Tectonic evolution of the Andes of Neuquén: constraints derived from the magmatic arc and foreland deformation. In *The Neuquén Basin: A Case Study in Sequence Stratigraphy and Basin Dynamics* (Veiga, G.; Spalletti, L.A.; Howell, J.A.; Schwarz, E.; editors). Geological Society, Special Publications 252: 15-35. London.
- Sempere, T. 1995. Phanerozoic evolution of Bolivia and adjacent regions. In *Petroleum Basins of South America* (Tankard, A.J.; Suárez, R.S.; Welsink, H.J.; editors). American Association of Petroleum Geologists, Memoir 62: 207-230. Tulsa.
- SERNAGEOMIN, 2003. Mapa Geológico de Chile, escala 1:1.000.000. Servicio Nacional de Geología y Minería, Publicación Geológica Digital No. 4. Santiago
- Silvestro, J.; Kraemer, P.; Achilli, F.; Brinkworth, W. 2005. Evolución de las cuencas sinorogénicas de la Cordillera Principal entre 35-36°S, Malargüe. *Revista de la Asociación Geológica Argentina* 60 (4): 627-643.
- Somoza, R.; Zaffarana, C.B. 2008. Mid-Cretaceous polar standstill of South America, motion of the Atlantic hotspots and the birth of the Andean cordillera. *Earth and Planetary Science Letters* 271: 267-277.
- Spikings, R.; Dungan, M.; Foeken, J.; Carter, A.; Page, L.; Stuart, F. 2008. Tectonic response of the central Chilean margin (35-38°S) to the collision and subduction of heterogeneous oceanic crust: a thermochronological study. *Journal of the Geological Society of London* 165: 941-953.
- Sruoga, P.; Etcheverría, M.P.; Folguera, A.; Repol, D.; Cortés, J.M.; Zanettini, J.C. 2005. Hoja Geológica 3569-I Volcán Maipo, Provincia de Mendoza. Instituto de Geología y Recursos Minerales, Servicio Geológico Minero Argentino, Boletín 290: 92 p. Buenos Aires.
- Steinmann, G. 1929. *Geologie von Perú*. Karl Winter: 448 p. Heidelberg.
- Stipanovic, P.N.; Rodrigo, F. 1970. El diastrofismo eo- y mesocretácico en Argentina y Chile, con referencias a los movimientos jurásicos de la Patagonia. In *Jornadas Geológicas Argentinas*, No. 4, Actas 2: 334-352. Buenos Aires.
- Tunik, M. 2003. Interpretación paleoambiental de la Formación Saldeño (Cretácico superior), en la Alta Cordillera de Mendoza, Argentina. *Revista de la Asociación Geológica Argentina* 58 (3): 417-433.
- Tunik, M.; Folguera, A.; Naipauer, M.; Pimentel, M.; Ramos, V.A. 2010. Early uplift and orogenic deformation in the Neuquen basin: Constraints on the Andean uplift from U-Pb and Hf isotopic data of detrital zircons. *Tectonophysics* 489: 258-273.

- Uliana, M.A.; Biddle, K.T. 1988. Mesozoic-Cenozoic paleogeographic and geodynamic evolution of southern South America. *Revista Brasileira de Geociencias* 18 (2): 172-190.
- Veiga, G.D.; Spalletti, L.A.; Howell, J.A.; Schwarz, E. (editors). 2005. The Neuquén basin: a case study in sequence stratigraphy and basin dynamics. *Geological Society, Special Publications* 252: 344 p. London.
- Vicente, J.C.; Sequeiros, F.; Valdivia, M.A.; Zavala, J. 1979. El sobre-escurrimiento de Cincha- Luta: elemento del accidente mayor andino al NW de Arequipa. *Sociedad Geológica de Perú. Boletín* 61: 67-100.
- Vicente, J.C. 2005. La fase primordial de estructuración de la faja plegada y corrida del Aconcagua: importancia de la fase Pehuenche del Mioceno inferior. *Revista de la Asociación Geológica Argentina* 60 (4): 672-684.
- Waite, K. 2005. Low-grade metamorphism and fission-track analysis in the Main Cordillera of the Andes -Central Chile, 35°S. Ph.D. Thesis (Unpublished), Universität Basel: 154 p.
- Weaver, C. 1927. The Roca Formation in Argentina. *American Journal of Science* 13: 417-434.
- Wichmann, R. 1934. Contribución al conocimiento geológico de los territorios del Neuquén y del Río Negro. Dirección General de Minas y Geología, Ministerio de Agricultura, *Boletín* 39: 1-27. Buenos Aires.
- Zamora Valcarce, G.; Zapata, T.; del Pino, D.; Ansa, A. 2006. Structural evolution and magmatic characteristics of the Agrio fold-and-thrust belt. In *Evolution of an Andean margin: A tectonic and magmatic view from the Andes to the Neuquén Basin (35-39°S lat.)* (Kay, S.M.; Ramos, V.A.; editors). *Geological Society of America, Special Paper* 407: 125-145. doi:10.1130/2006.2407(06)
- Zapata, T.R.; Córscico, S.; Dzelalija, F.; Zamora, G. 2002. La faja plegada y corrida del Agrio: análisis estructural y su relación con los estratos terciarios de la cuenca neuquina, Argentina. In *Congreso de Exploración y Desarrollo de Hidrocarburos*, No. 5, Actas, Electronic files: 10 p. Mar del Plata.